NHTSA's Handling and ESC 2004 Research Program:

An Update

December 3 , 2004

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NHTSA VRTC

Program Objectives

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- **Objectives are twofold:**
  - **Develop a handling-based "rating" metric**
  - **Perform light vehicle ESC research**
- **Vehicle selection has allowed both items to be considered concurrently**

Focus of this presentation

Test Vehicles

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- Each vehicle was evaluated with ESC enabled and disabled
- Two SUVs
  - 2004 Volvo XC90
  - 2003 Toyota 4Runner
- Two Passenger Cars
  - 2003 Toyota Camry
  - 2002 Chevrolet Corvette
- One 15-Passenger Van
  - 2004 GMC Savana 3500

Four Maneuver Groups
(Test Groups 1-3 are complete)

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- **Test Group 1**
  - Rollover maneuvers, Slowly Increasing Steer
  - Steering machine inputs
- **Test Group 2**
  - Dry and wet lane-changes, 200-ft radius circle
  - Up to four drivers
- **Test Group 3**
  - Alliance handling maneuvers
  - New NHTSA maneuvers
  - Steering machine inputs
- **Test Group 4**
  - Some Group 3 maneuvers performed with load
    - Rear GAWR
    - Vehicle GVWR
  - Winter '04 completion

Discussed in this presentation

Test Group 3
Performed With A Steering Machine

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Maneuver	Throttle Application	Surface	Entrance Speed
Pulse Steer (two rates)	Released Before Steering Begins	Dry Asphalt	65 mph
Single Cycle Sinusoids (four frequencies)	Released Before Steering Begins	Dry Asphalt	50 mph
Single Cycle Sinusoid with Dwell (two frequencies)	Released Before Steering Begins	Dry Asphalt	50 mph
Single Cycle Sinusoid with Increasing Amplitude (three frequencies)	Released Before Steering Begins	Dry Asphalt	50 mph
Reverse Steer with Yaw Acceleration Feedback (two rates)	Released Before Steering Begins	Dry Asphalt	50 mph
Reverse Steer with Increasing Amplitude and Yaw Acceleration Feedback (two rates)	Released Before Steering Begins	Dry Asphalt	50 mph
Closing Radius Turn	Released Before Steering Begins	Dry Asphalt	Max Attainable (up to 60 mph)

Maneuver Description

Yaw Acceleration Steering Reversals

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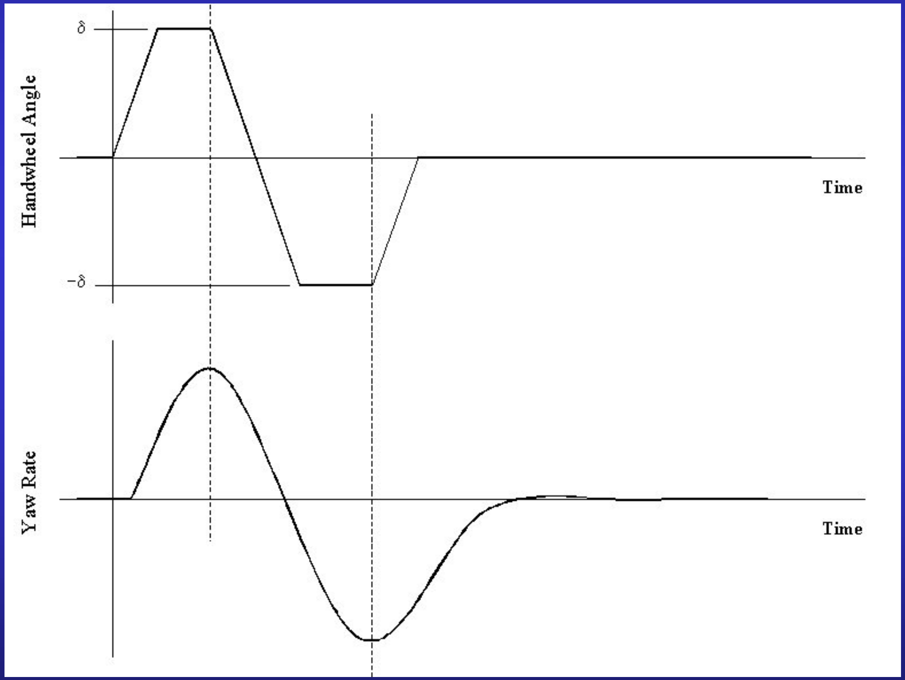
- **Steering Reversals both initiated at peak yaw rate**
- **SWA increased in 20-deg increments**
- **Two rates examined**
  - **500 deg/sec**
  - **720 deg/sec**
- **Maneuvers intended to maximize yaw response for <u>all</u> light vehicles**



Maneuver Description

Yaw Accel Steering Reversal Variations

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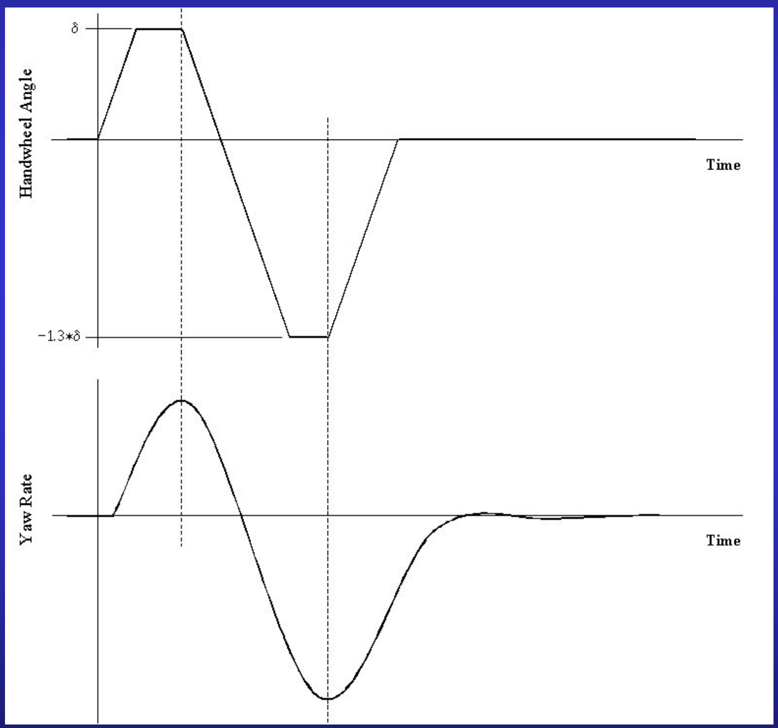
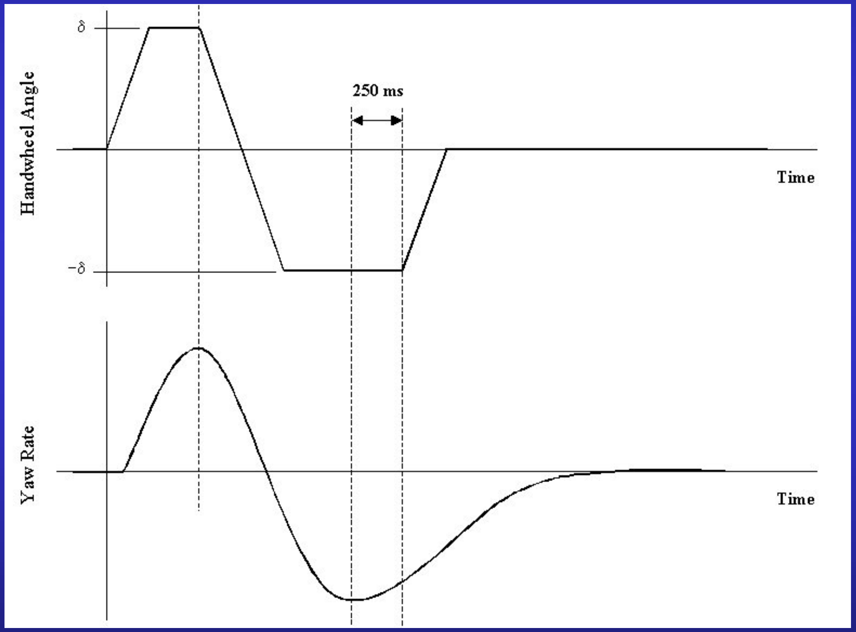


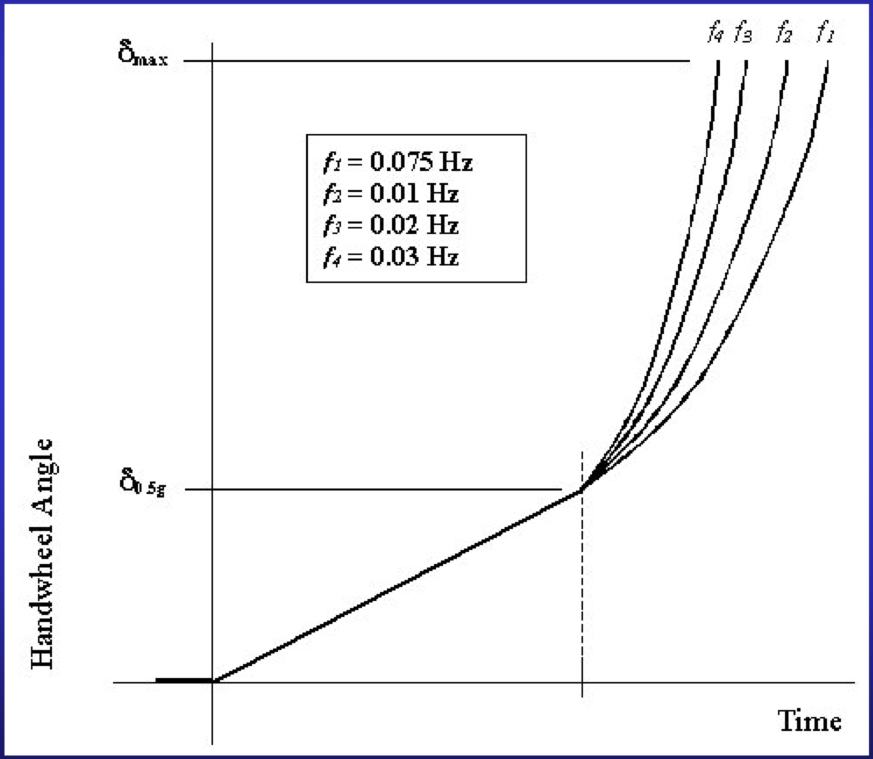
Increasing Amplitude



With 250 ms Pause

Maneuver Description
Closing Radius Turn (Exit Ramp)

- Simulates a real-world scenario
- Intended to evaluate understeer mitigation strategies
- Three SWA magnitudes
  - 1.5*$SWA_{90\%\ Peak\ AY\ from\ SIS}$
  - 2.0*$SWA_{90\%\ Peak\ AY\ from\ SIS}$
  - 360 degrees
- Partial sine w/four frequencies
  - 0.075 Hz
  - 0.1 Hz
  - 0.2 Hz
  - 0.3 Hz



Preliminary Results
Test Group 3

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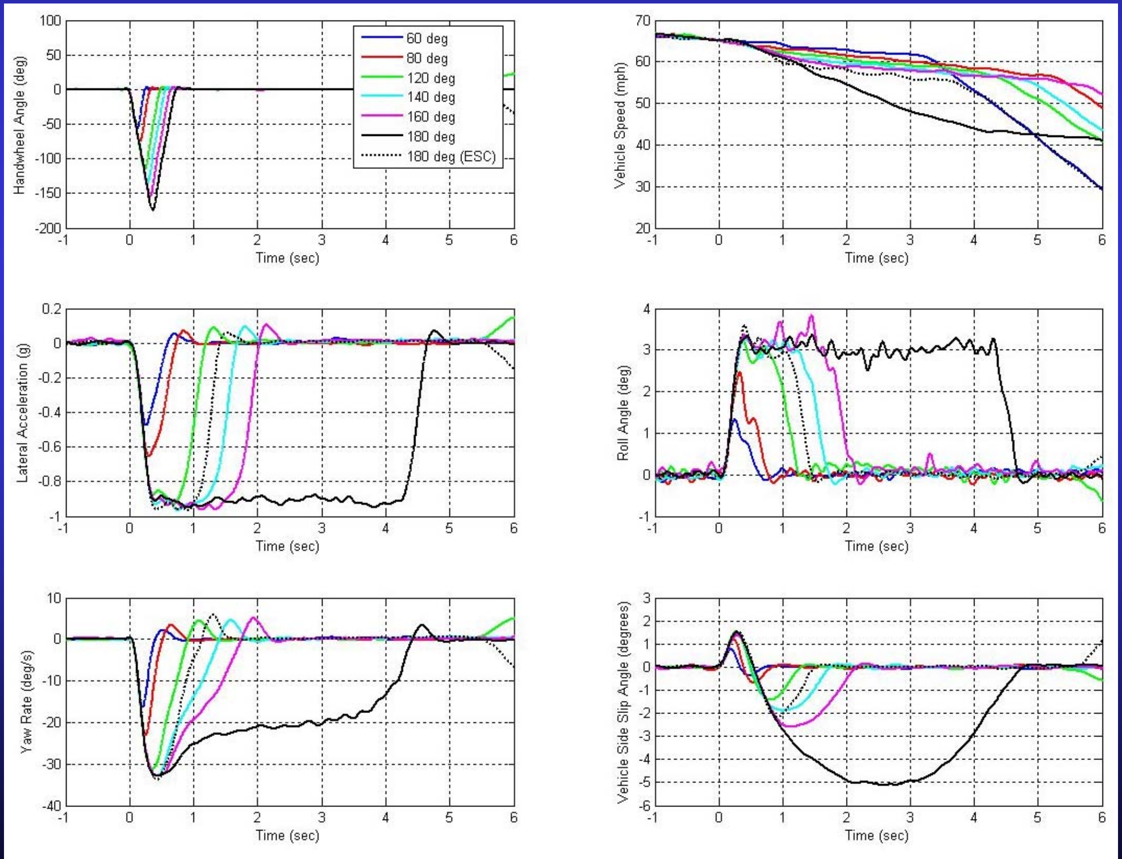
- **Alliance / NHTSA, pulse / steering reversal maneuvers able to spin all test vehicles without ESC; *some spinouts with ESC***
  - One or more of these maneuvers may provide NHTSA with the ability to <u>test</u> whether a vehicle is equipped with an effective ESC
- **Simulated Exit Ramp Maneuver may provide a way of quantifying ESC understeer mitigation**
  - Understeer mitigation should not “upset the vehicle”

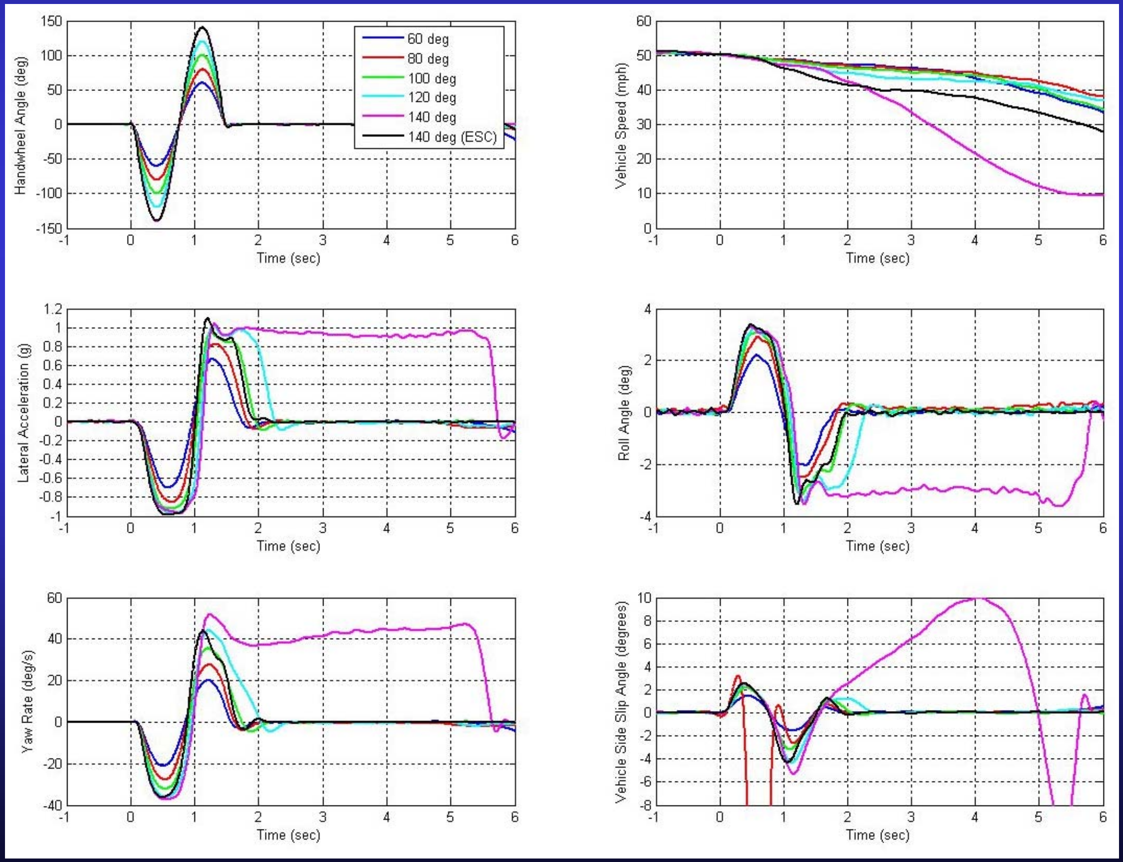
Sample Data (Corvette)
Test Group 3

Pulse Steer, Ramp Rate = 500 deg/sec
ESC Disabled



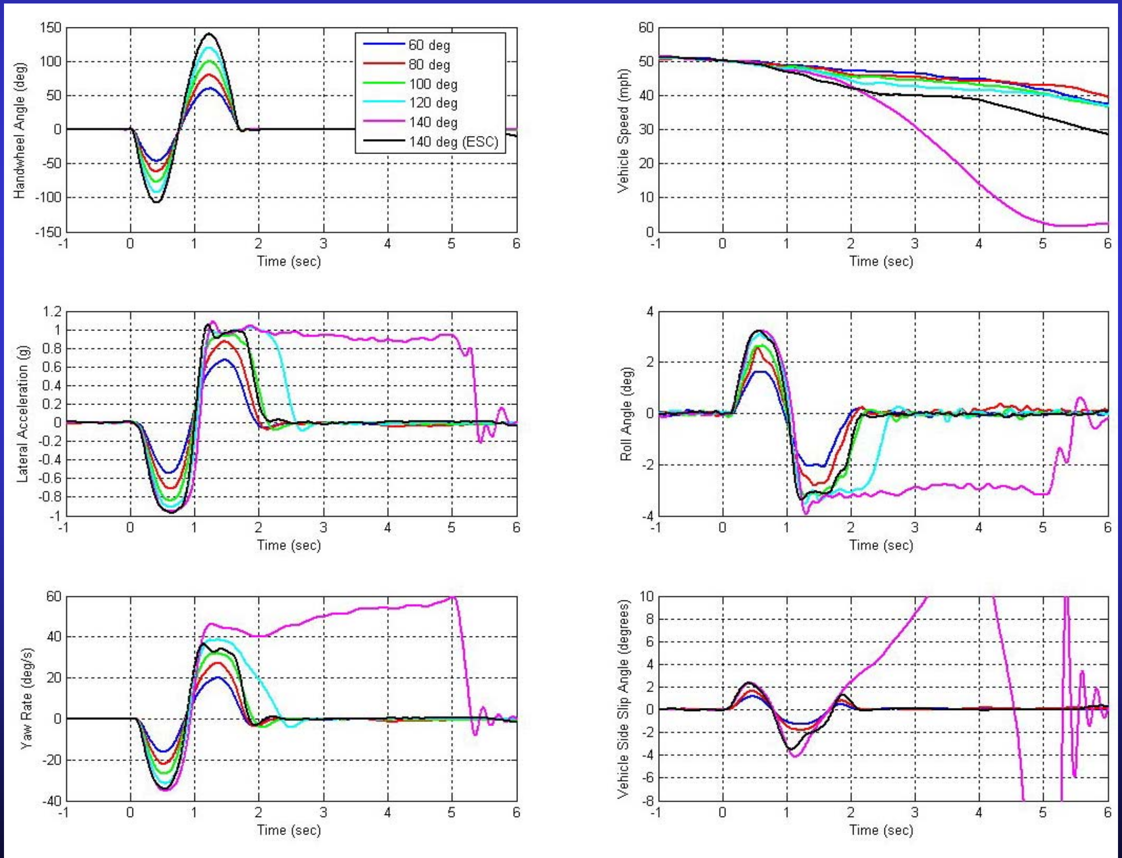
Sample Data (Corvette)
Test Group 3

Sine Steer, Commanded Frequency = 0.7 Hz
ESC Disabled



Sample Data (Corvette)
Test Group 3

Increasing Amplitude Sine Steer, Commanded Frequency = 0.7 Hz
ESC Disabled



Sample Data (Corvette)
Test Group 3

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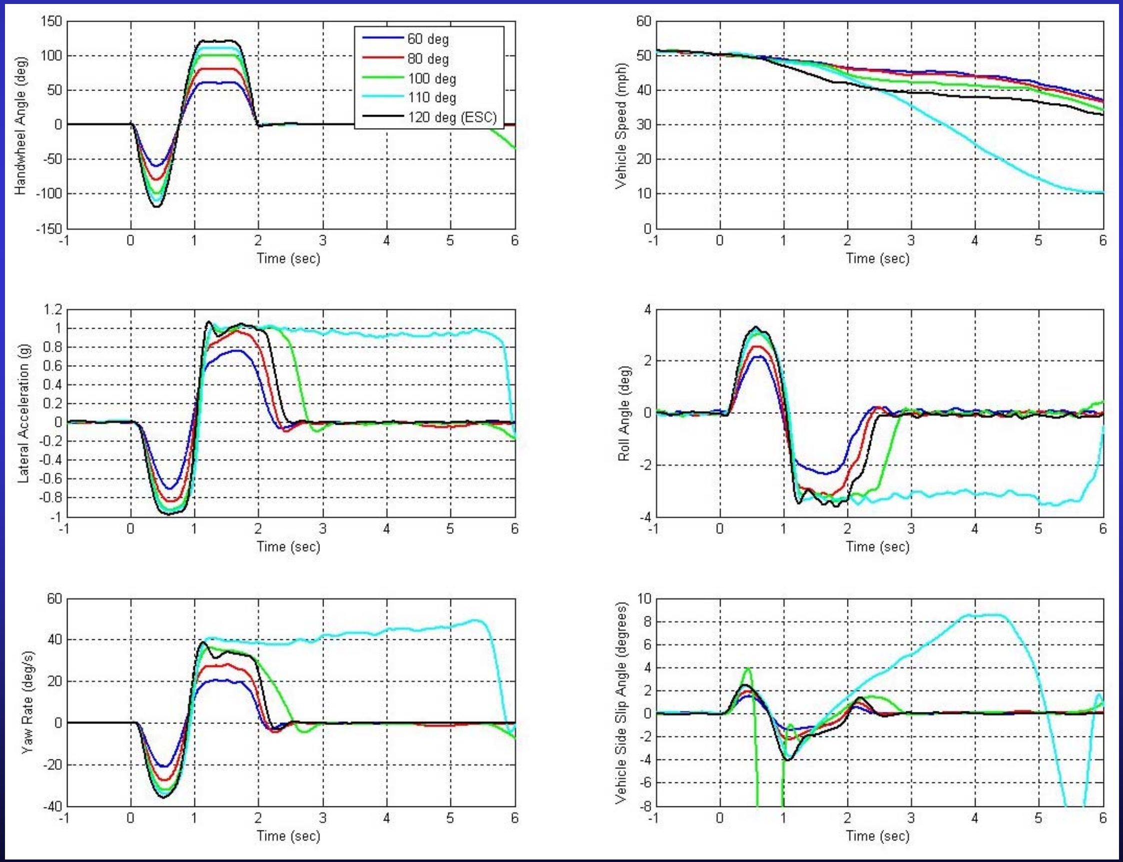
Sine Steer with 500ms Dwell, Commanded Frequency = 0.7 Hz
ESC Disabled



Sample Data (Corvette)
Test Group 3

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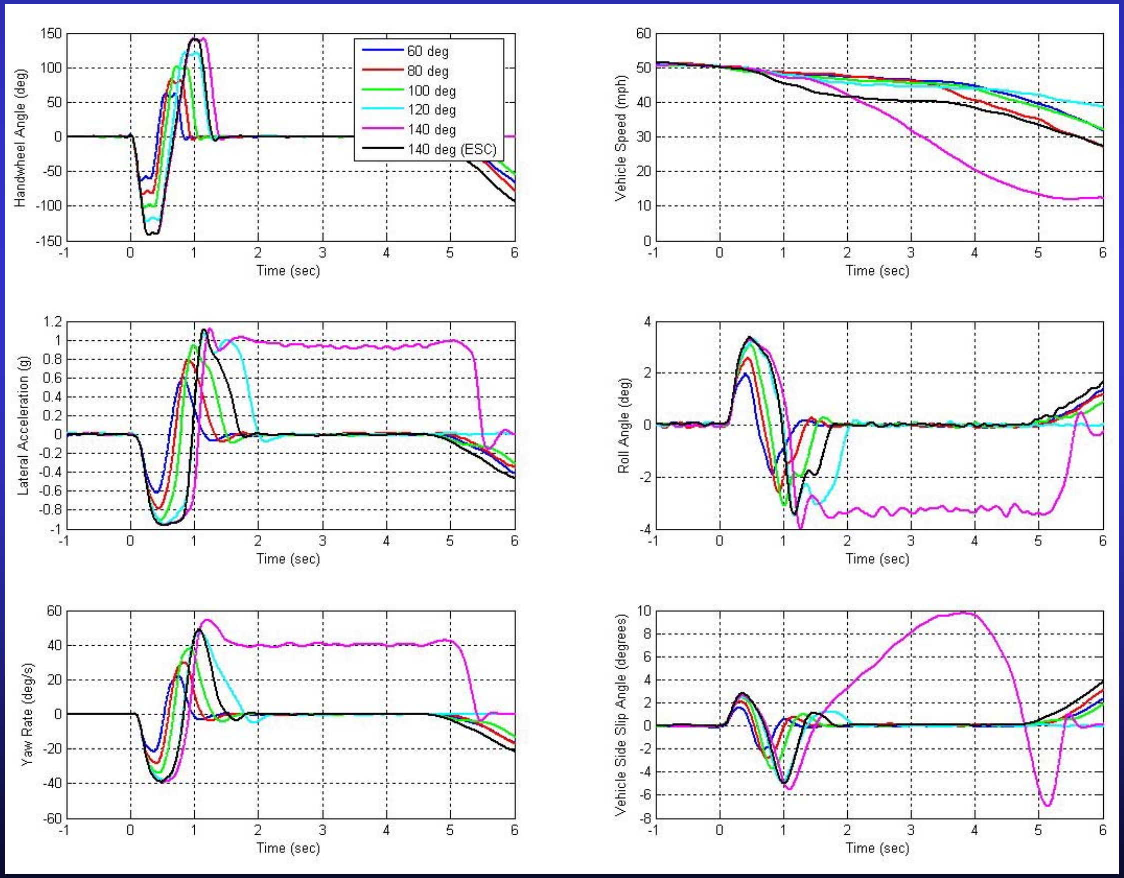
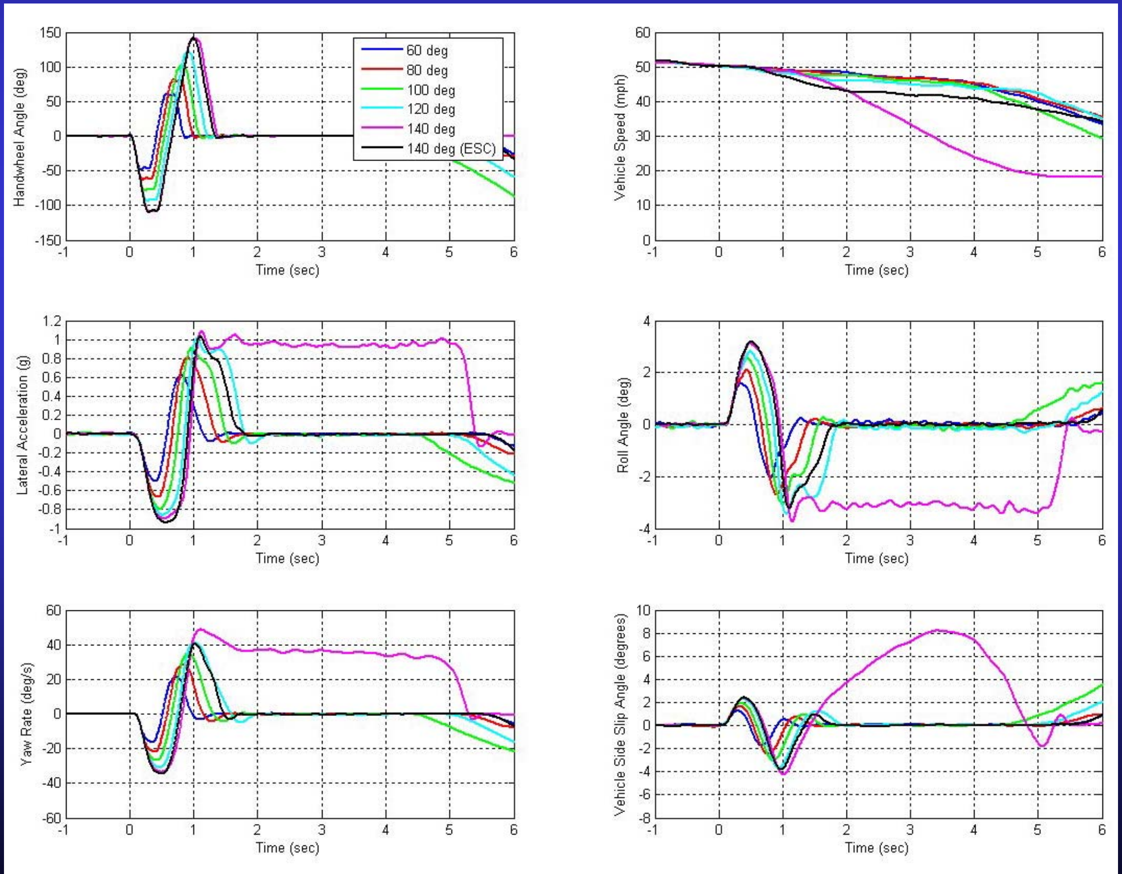
Steering Reversal with YAF, Symmetric Amplitude, 500 deg/sec
ESC Disabled



Sample Data (Corvette)
Test Group 3

Steering Reversal with YAF, Increasing Amplitude, 500 deg/sec
ESC Disabled



Sample Data (Camry)
Test Group 3

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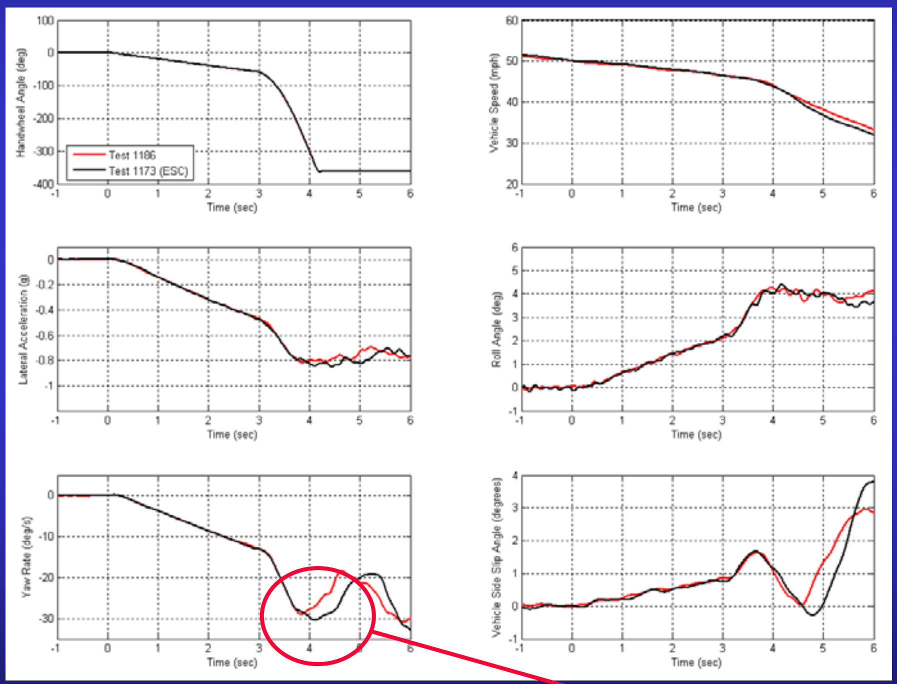
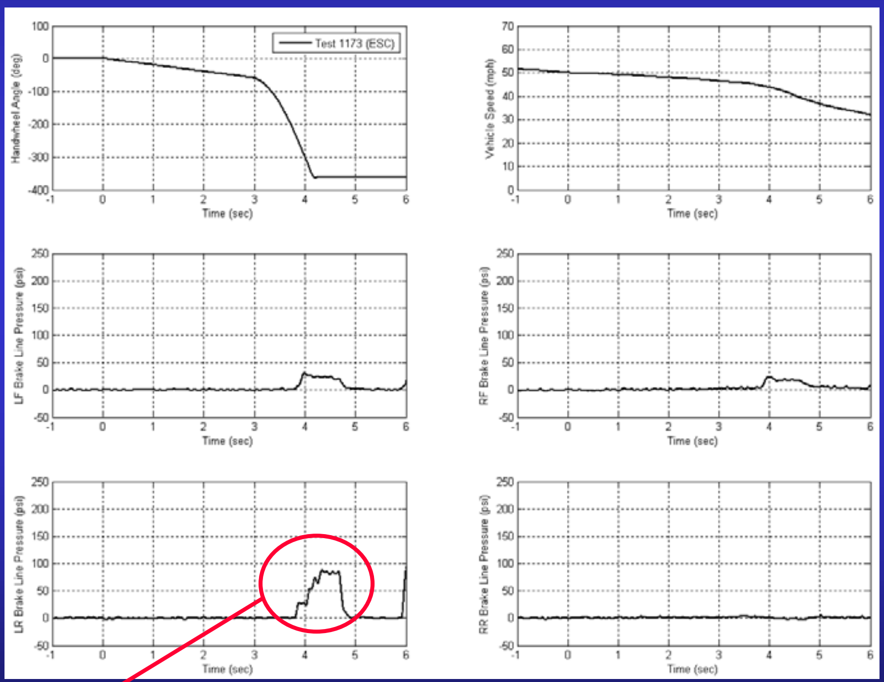
Exit Ramp Maneuver, 360 degree max steer

Red = No ESC, Black = ESC





Indication of slight understeer mitigation

ESC Effectiveness Research

What is ESC?

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- **Most beneficial attribute = reduction in the tendency to spinout**
  - **Detectable in crash data (I.e., skidding prior to crash without ESC)**
  - **Apparent in test track data**
  - **Difficult to formally define**

Mercedes:

"ESP lowers the risk of skidding [and]… stabilizes the vehicle in situations where the driving dynamics have reached a critical point."

Toyota:

Approximately 20% of serious accidents are caused by loss-of-control. A large number of these cases involved the vehicle skidding.

NHTSA:

"This technology appears to provide safety benefits by reducing the number of crashes due to driver error and loss of control..."

Definition is presently under development (later slides discuss in detail)

Identifying ESC

- An ESC-equipped vehicle should not spinout in a nominal load configuration
  – Requires a definition of “spinout”
- Three potential maneuvers
  – Sine with Dwell (0.7 Hz)
  – Yaw Acceleration Steering Reversal
  – Yaw Acceleration Steering Reversal, 250 ms pause

Sine with Dwell (0.7 Hz)

- Pros
  - Able to effectively produce spinouts with low-to-moderate handwheel angles
  - Use of a pause helps the vehicle “catch-up” to the steering inputs late in the maneuver
- Cons
  - Set frequency may not excite yaw motion of all light vehicles to the same extent
  - Handwheel rates become very high with large steering angle amplitudes

Yaw Acceleration Steering Reversal

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- Pros
  - Able to effectively produce spinouts with low-to-moderate handwheel angles
  - Vehicle allowed to seek out its own yaw natural frequency
- Cons
  - Requires use of an angular accelerometer
  - Reversing direction of steer at maximum yaw rate does not necessarily insure a worst-case response

Yaw Acceleration Steering Reversal w/Pause

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- **Pros**
  - Able to effectively produce spinouts with low-to-moderate handwheel angles
  - Vehicle allowed to seek out its own yaw natural frequency
  - Use of a pause helps the vehicle “catch-up” to the steering inputs late in the maneuver
- **Cons**
  - Requires use of an angular accelerometer
  - Only limited testing performed

Test Group 3 Sample Data:
Steering Angle Comparison

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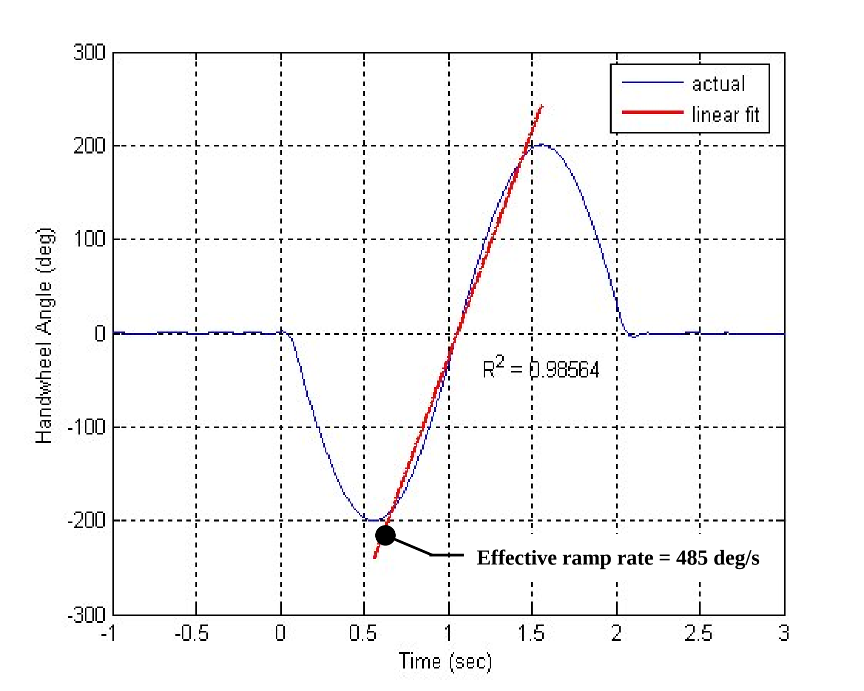
Vehicle	Maneuver															
	Pulse Steer		Sine Steer (Pure Sine)				Sine with Dwell		Increasing Amplitude Sine Steer			Yaw Acceleration Steering Reversal (Symmetric Steer)		Increasing Amplitude Yaw Acceleration Steering Reversal	
	500 deg/s	700 deg/s	0.5 Hz	0.6 Hz	0.7 Hz	0.8 Hz	0.5 Hz	0.7 Hz	0.5 Hz	0.6 Hz	0.7 Hz	500 deg/s	720 deg/s	500 deg/s	720 deg/s
2004 Volvo XC90 4x4	200 (0746)	240 (1007)	140 (0946)	150 (0940)	170 (0865)	180[1] (0858)	130 (0790)	130 (0984)	160 (0954)	160 (0960)	160 (0966)	140 (1068)	140 (1073)	160 (1079)	160 (1084)
2004 GMC Savana 3500	240[2] (0864)	280 (0877)	240 (1079)	300 (1092)	**N/A (1105)**	**N/A (1118)**	170 (0912)	190 (0922)	220 (1127)	240 (1138)	290 (1152)	200 (1190)	240 (1200)	220 (1235)	220 (1244)
2003 Toyota Camry	240 (0941)	260 (0952)	170 (1016)	210 (1026)	230 (1036)	270 (1048)	160 (1068)	160 (1159)	210 (1134)	200 (1143)	200 (1151)	180 (1249)	200 (1257)	180[2] (1264)	200 (1272)
2003 Toyota 4Runner 4x4	200[2] (0625)	300 (0638)	180 (0703)	180 (0710)	200 (0719)	210 (0728)	180 (0968)	170 (0975)	210 (0780)	210 (0789)	200 (0798)	180 (0865)	180 (0872)	200 (0880)	200 (0888)
2002 Chevrolet Corvette	180 (0458)	220 (0468)	120 (0473)	140 (0478)	140 (0483)	160 (0490)	120 (0494)	110 (0498)	140 (0504)	130 (0509)	140 (0515)	140 (0681)	140 (0728)	140 (0705)	160 (0717)

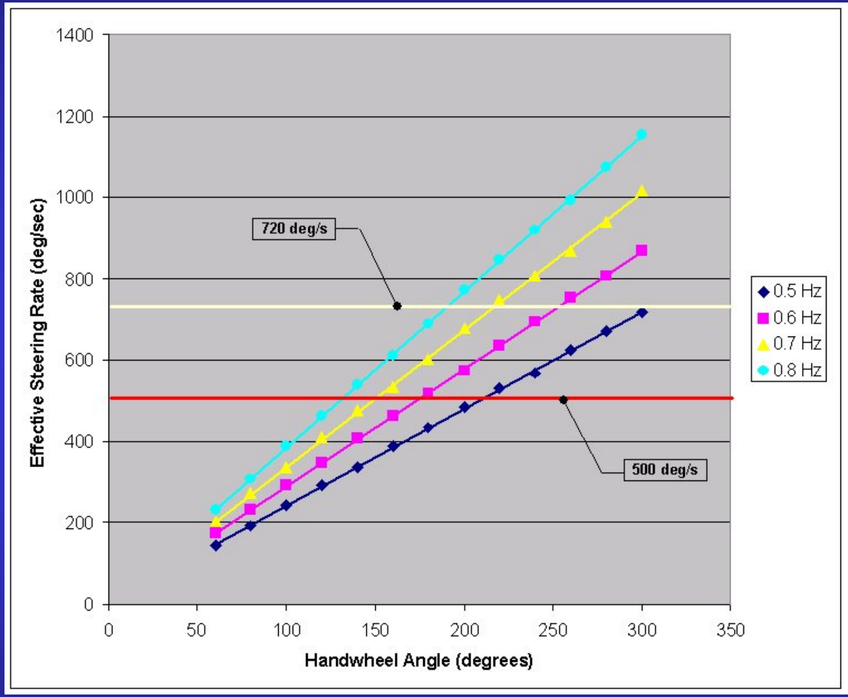
[1]Vehicle's final heading was 80 degrees from the initial path.

[2]Vehicle's final heading was 85 degrees from the initial path.

Data produced during disabled ESC tests

Test Group 3 Sample Data:
Effective Sine Steer Rates





0.5 Hz Sine Steer, SWA = 200 degrees

Question: *Should the "ESC maneuver" be comprised of increasing steer angles and constant rates (e.g., 500 deg/sec Yaw Acceleration Steering Reversal) or increasing rates (e.g., 0.7 Hz Sine with Dwell)?*

Output Comparison
Peak Yaw Rate vs. SWA

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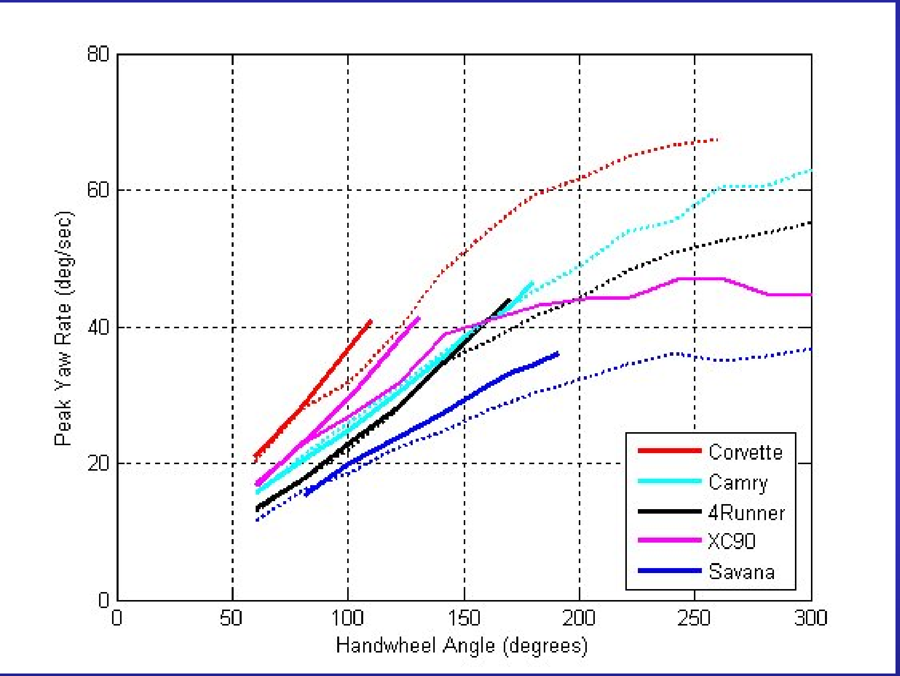
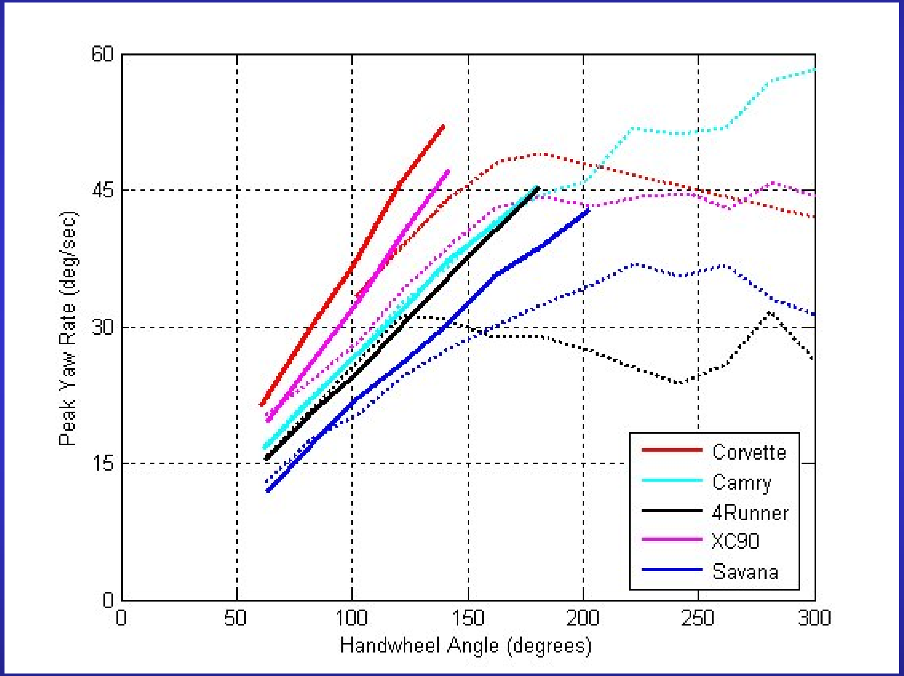
0.7 Hz SWD



500 deg/sec YASR



Dotted lines = tests performed with ESC enabled

Different vehicles achieve different peak yaw rates for a given SWA

Output Comparison
Includes YASR w/250 ms pause

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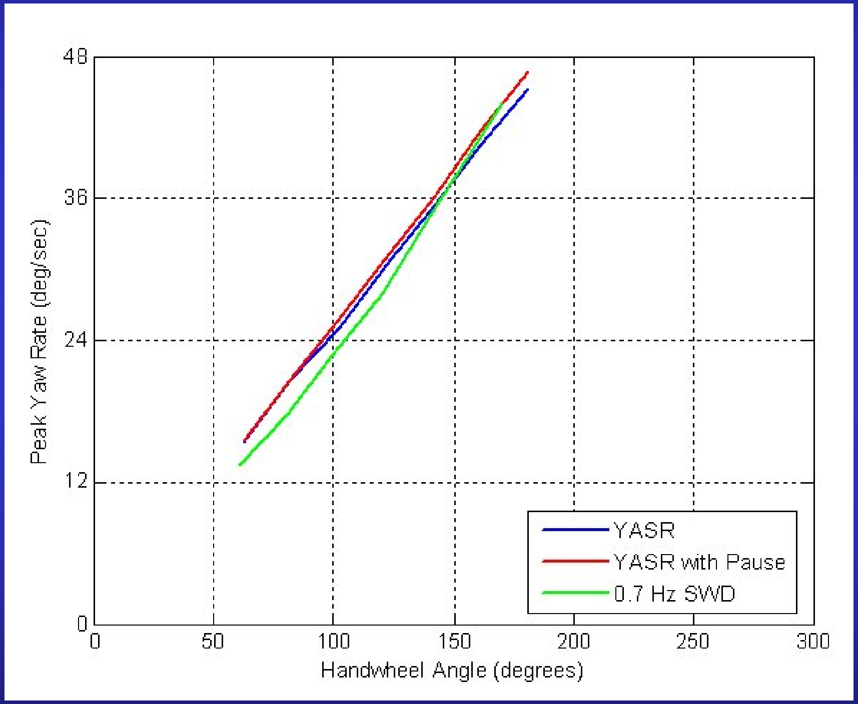

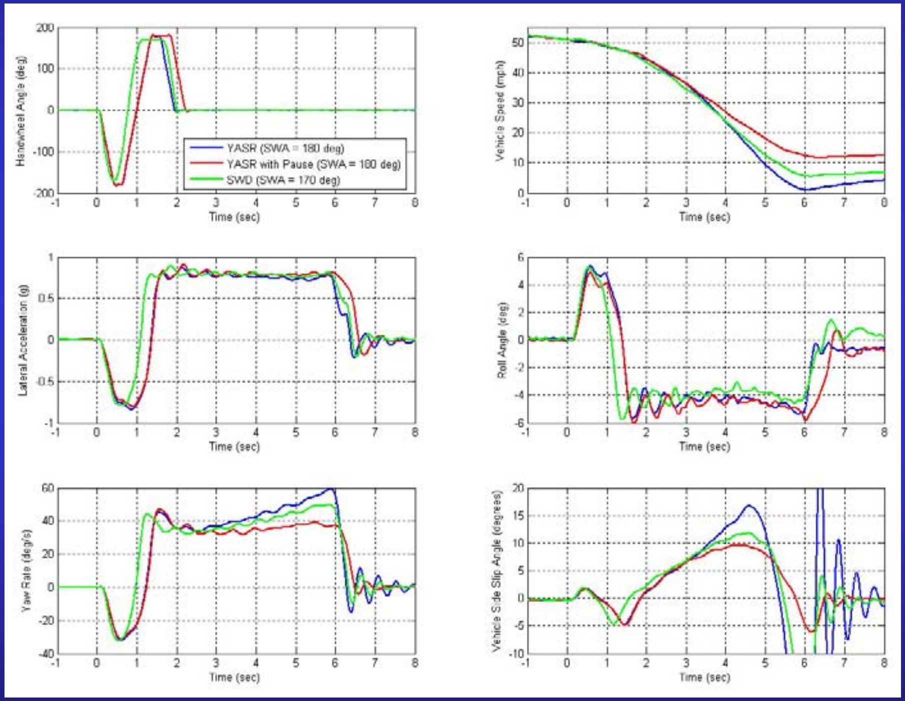

Example: 2003 4Runner 4x4

What is a "Spinout"
Data Collection

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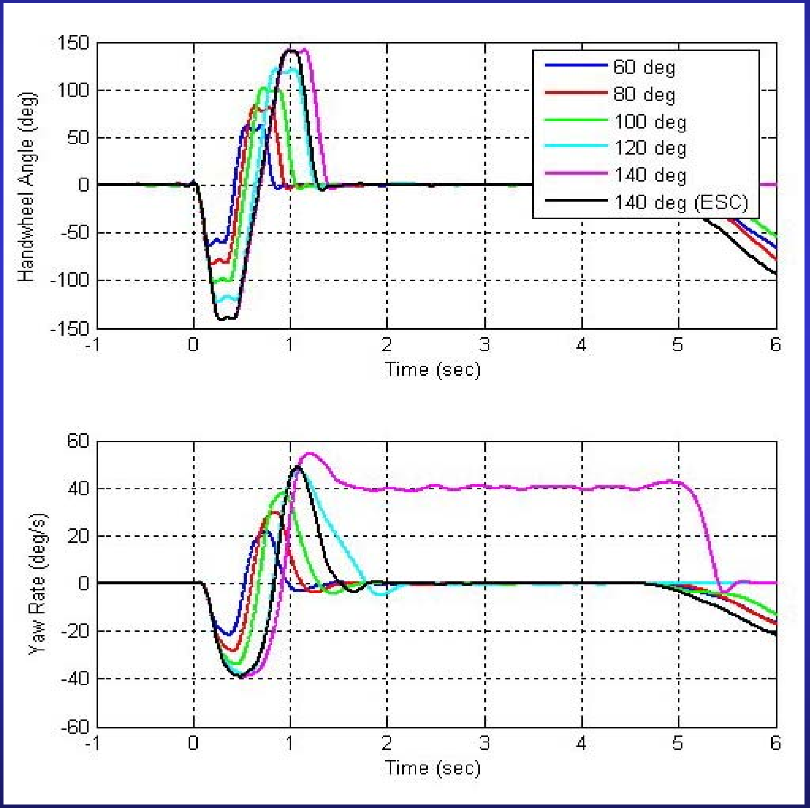
- Alliance and NHTSA maneuvers capable of producing oversteer were performed
  - Pulse Steer
  - Sine Steer
  - Sine with Dwell
  - Increasing Amplitude Sine
  - Yaw Acceleration Steering Reversals
- SWA increased until vehicle's final heading was ≥ 90 degrees from initial path, then test terminated
- Results used to form two groups
  - Final heading < 90 degrees
  - Final heading ≥ 90 degrees

What is a "Spinout"
Analysis Concept

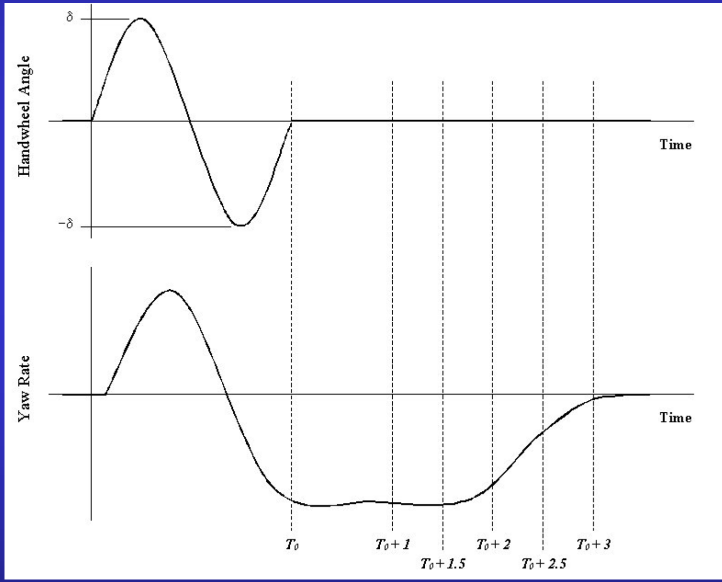
- **Many responses and relationships considered**
- **Relationship between SWA and yaw rate believed to provide the best description**
- **Question:** *How can yaw rate be used to predict spinout?*
- **Answer:** *Determine how much yaw rate is present at some time after completion of the steering input (SWA = 0)*



Note differences with ESC enabled and disabled

What is a "Spinout"
Analysis Method

- **Results from test track were assigned a binary classification**
  - **Final heading < 90 degrees: (0)**
  - **Final heading ≥ 90 degrees: (1)**
- **Reference time = t_0**
- **Yaw rates at five time steps considered**
  - **t_0 + 1.0**
  - **t_0 + 1.5**
  - **t_0 + 2.0**
  - **t_0 + 2.5**
  - **t_0 + 3.0**
- **Percent of Peak Yaw Rate calculated at each time step**



What is a "Spinout"
Analysis Model

- SAS logistic regression model (SAS Genmod)
  - Used to determine how well the percent of peak yaw, measured at different time intervals, would predict the final heading (a binary outcome)
- Probabilities were computed at percentages of peak yaw between 35 and 100
- The percentage of peak yaw measured at t_0 + 1.0 provided the best prediction of outcome
  - The outcome was highly uncertain for only one of 11 selected points
  - All longer time intervals had more points associated with high uncertainty

What is a “Spinout”
Definition

$$Percent\ \dot{\psi}_{Peak} = 100 * \left(\frac{\dot{\psi}(t)}{\dot{\psi}_{Peak}} \right)$$

$$Set\ t = t_0 + 1$$

$$Spinout\ occurs\ if\ \ Percent\ \dot{\psi}_{Peak} \geq 60\%$$

What is a "Spinout"
Example of a uncertain prediction

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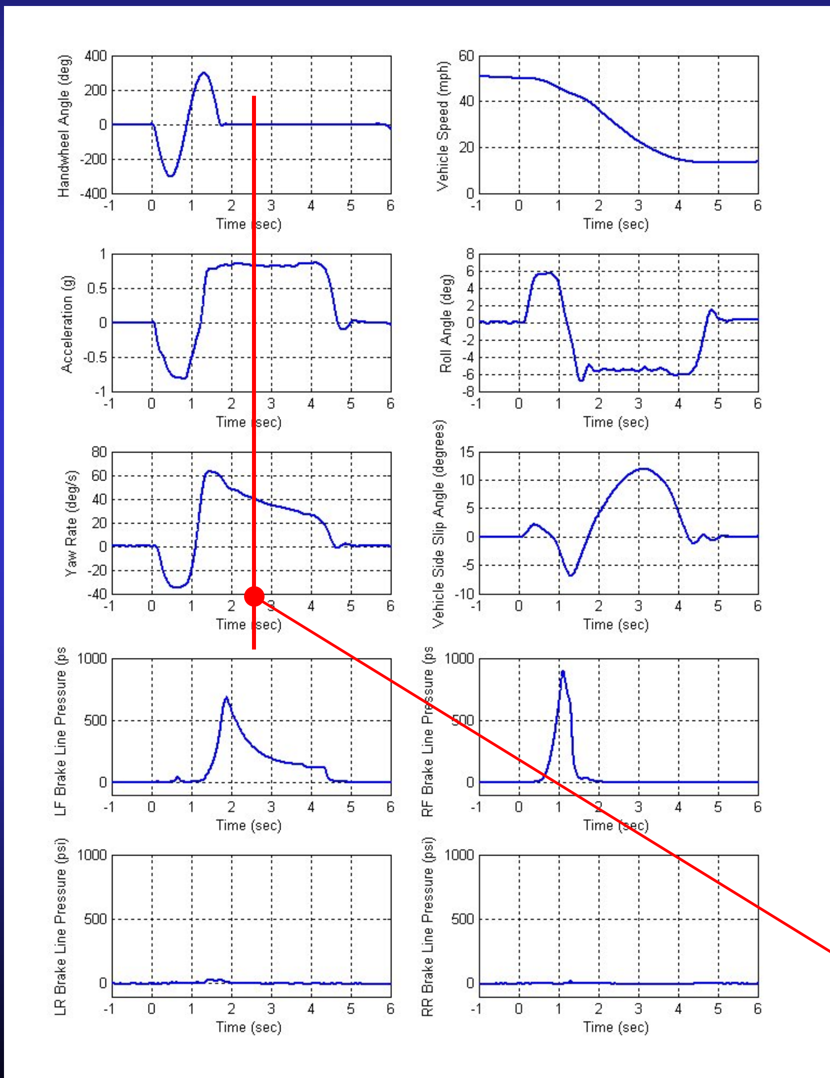

$$At\ t_0 + 1, Percent\ \dot{\psi}_{Peak} = 60.6$$

$t = t_0 + 1$

What is a “Spinout”

Advantages of NHTSA Definition

- Tests are easily performed
- Only basic instrumentation is required
  - No slip angle sensors
  - No GPS
- Spinout criterion can be assessed on the test track with little processing

ESC Evaluation Criterion

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- **In future testing VRTC will assess vehicle performance by determining whether a vehicle equipped with ESC spins out**
- **For the purpose of future research, VRTC's definition of spinout will be used**
- **Nominal load only**
- **Minimum lateral displacement?**
  (avoidability measure)
- **Method does not appear to penalize RSC-equipped vehicles**

Areas of Inquiry

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- Model used to predict spinout would benefit by the inclusion of more test data
- Maneuver selection opinions
- Conceptual feedback related to:
  - Yaw acceleration steering reversal tests
  - Spinout definition
  - ESC identification techniques
- Better measures of ESC effectiveness?

Key Points

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- ESC research is a top priority for NHTSA
- VRTC will assess vehicle performance by determining whether a vehicle equipped with ESC should not spinout
- A definition of spinout has been developed
- Potential maneuvers have been selected
- NHTSA seeks data to improve the robustness of its spinout model

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Supplemental Information

Test Group 1
Performed With A Steering Machine

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Maneuver	Throttle Application	Surface	Entrance Speed
Slowly Increasing Steer (to Max AY)	Applied as Needed	Dry Asphalt	50 mph
Road Edge Recovery (SS=6.5)	Released Before Steering Begins	Dry Asphalt	35 – 50 mph (or to TWL)
Road Edge Recovery (SS=5.5)	Released Before Steering Begins	Dry Asphalt	45 and 50 mph (or to TWL)
J-Turn (w/RER Steering Angles & Rates)	Released Before Steering Begins	Dry Asphalt	35 – 60 mph

Preliminary Results
Test Group 1

- ESC clearly affected how each vehicle responded to the SIS, J-Turn, and Fishhook maneuvers
- ESC “aggressivity” can be quantified by considering deceleration
- ESC did not necessarily reduce maximum lateral acceleration and roll angle
- Use of wet surfaces complicate testing

Test Group 1 Sample Data:
Toyota Camry, J-Turn

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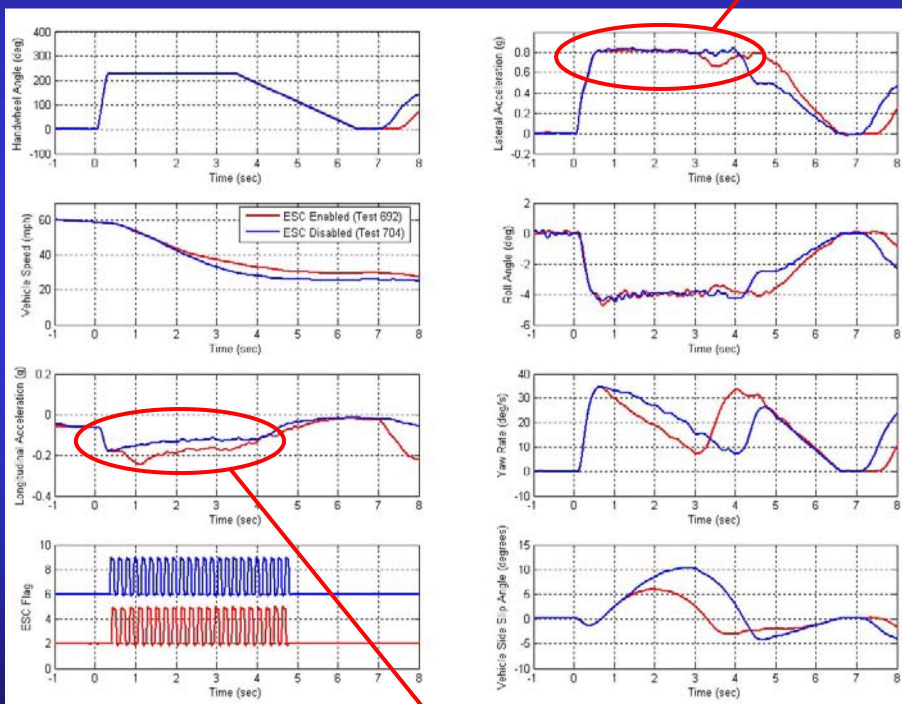
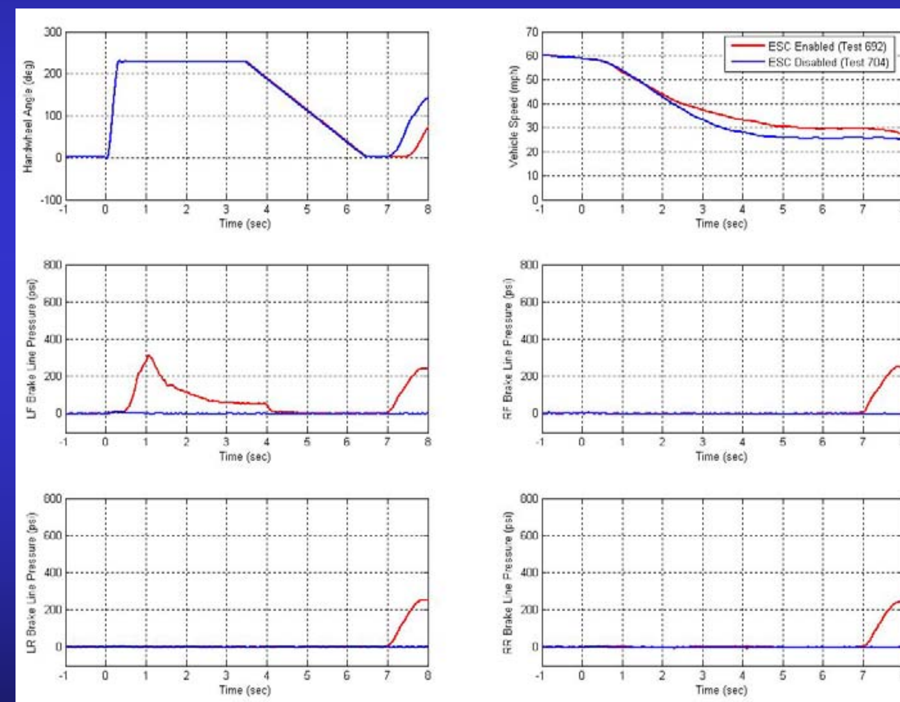
No significant reduction in AY_{max}

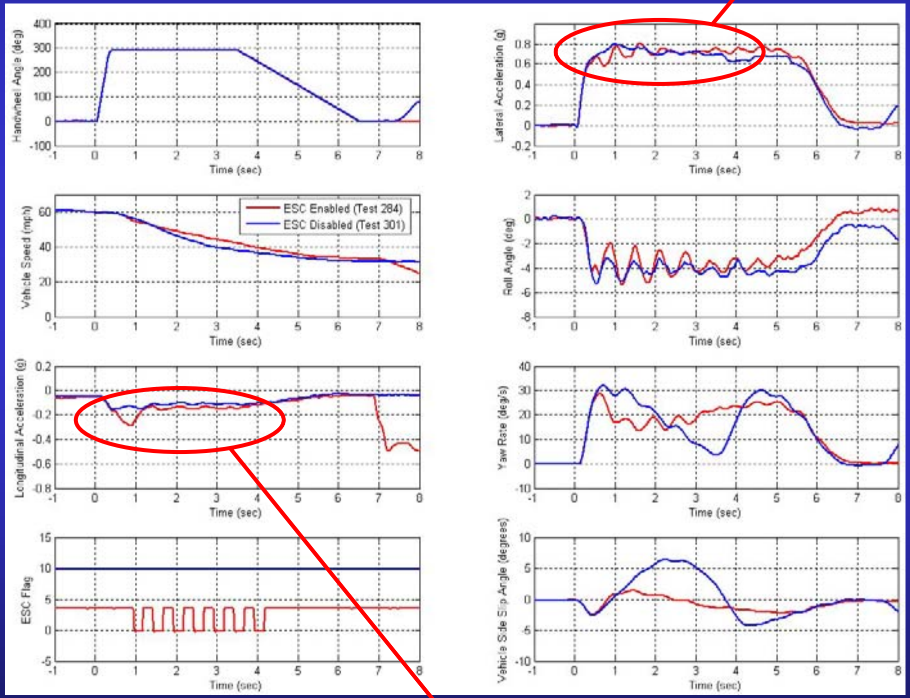


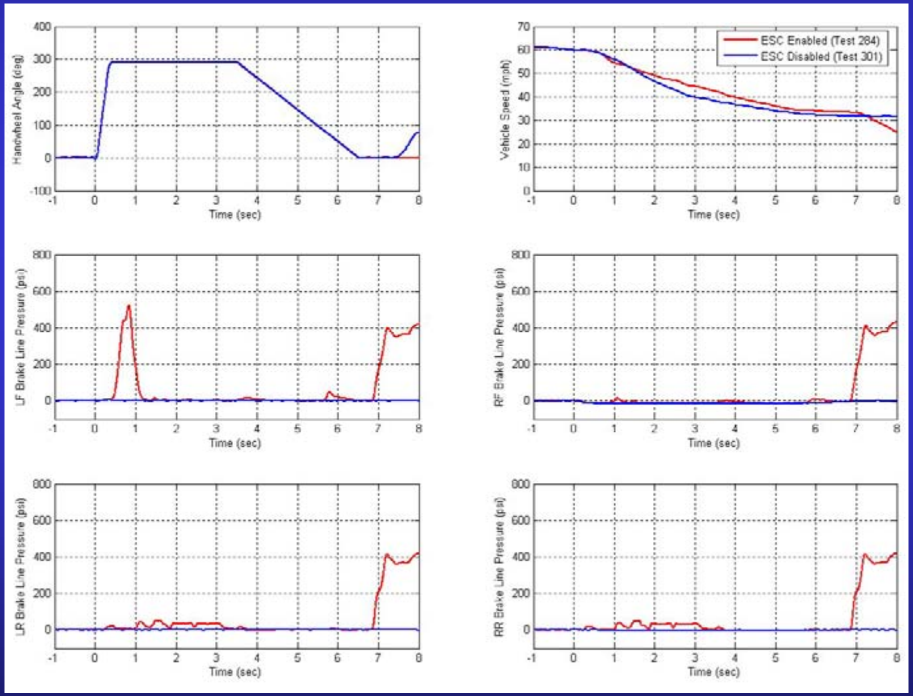


Small increase in decel

Test Group 1 Sample Data:
GMC Savana, J-Turn

Small initial reduction in AY





Small increase in decel

Test Group 1 Sample Data:
Chevrolet Corvette, J-Turn

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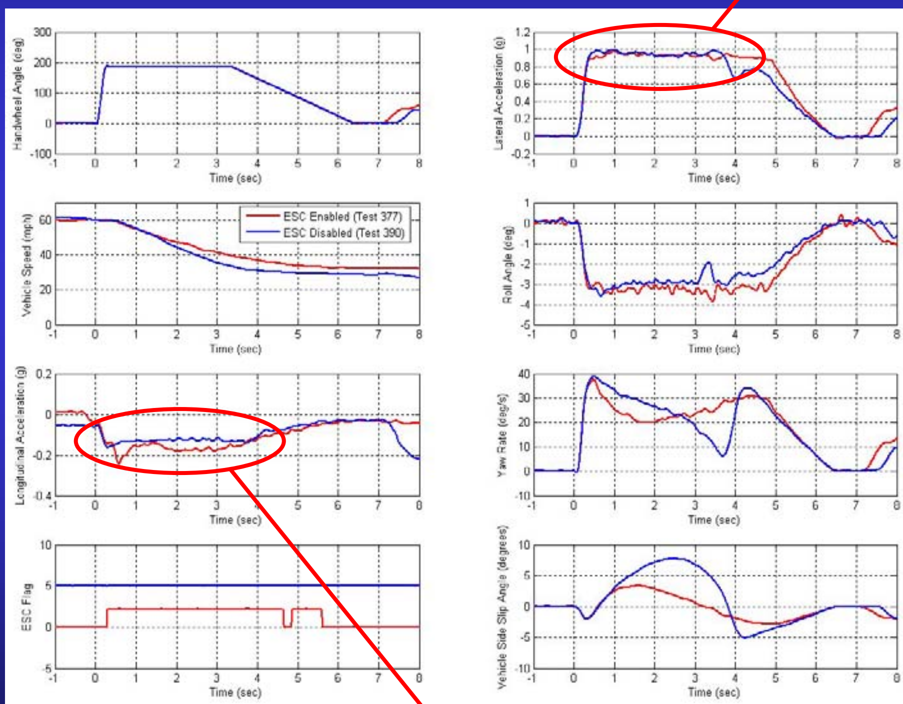
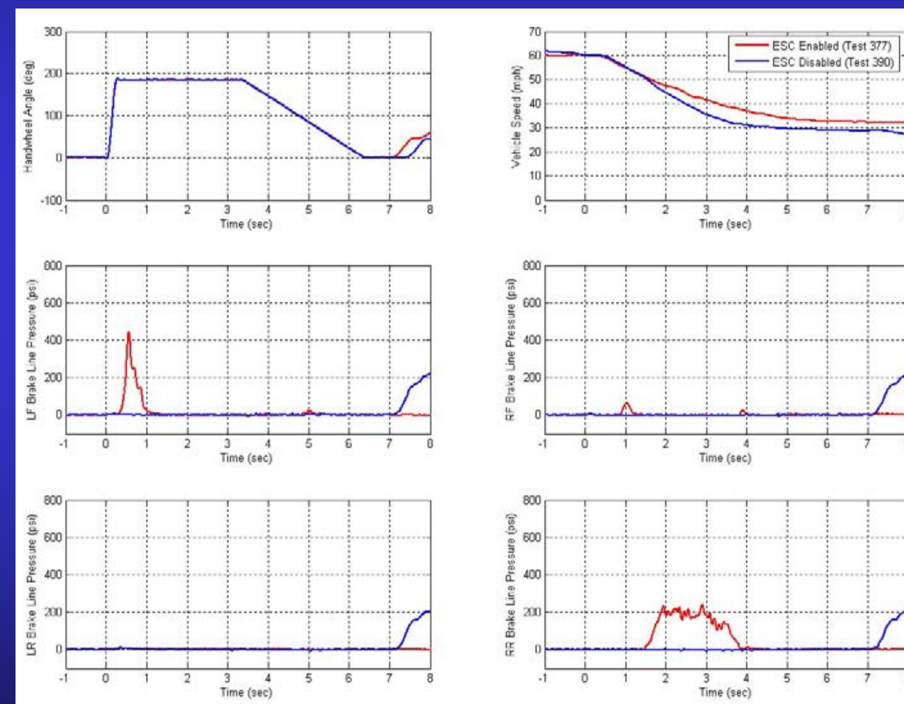
No significant reduction in AY_{max}

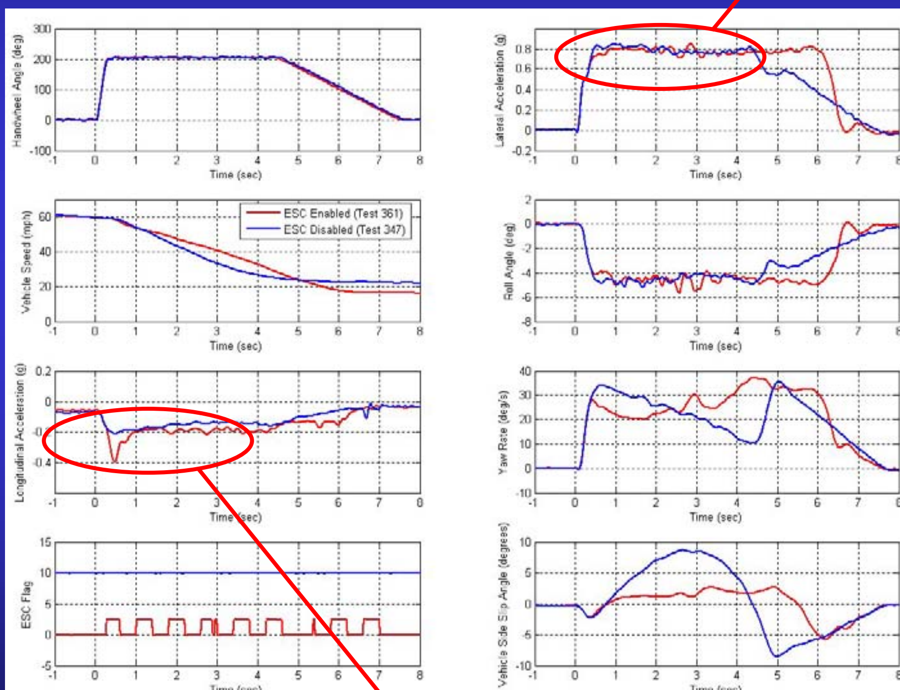


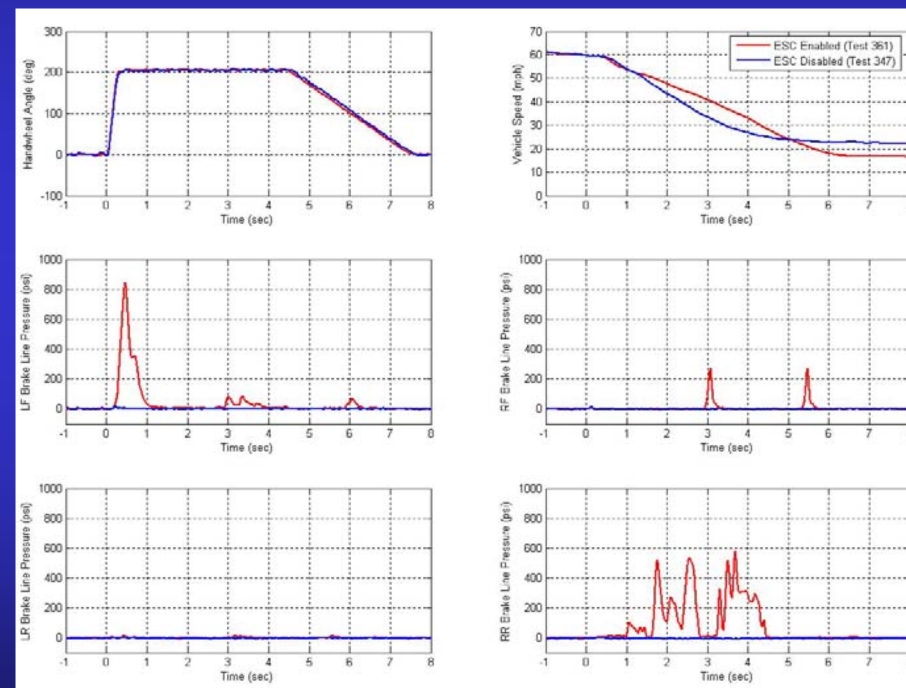


Small increase in decel

Test Group 1 Sample Data:
Volvo XC90, J-Turn

Small initial reduction in AY





Moderate increase in decel

Test Group 1 Sample Data:
Toyota 4Runner, J-Turn

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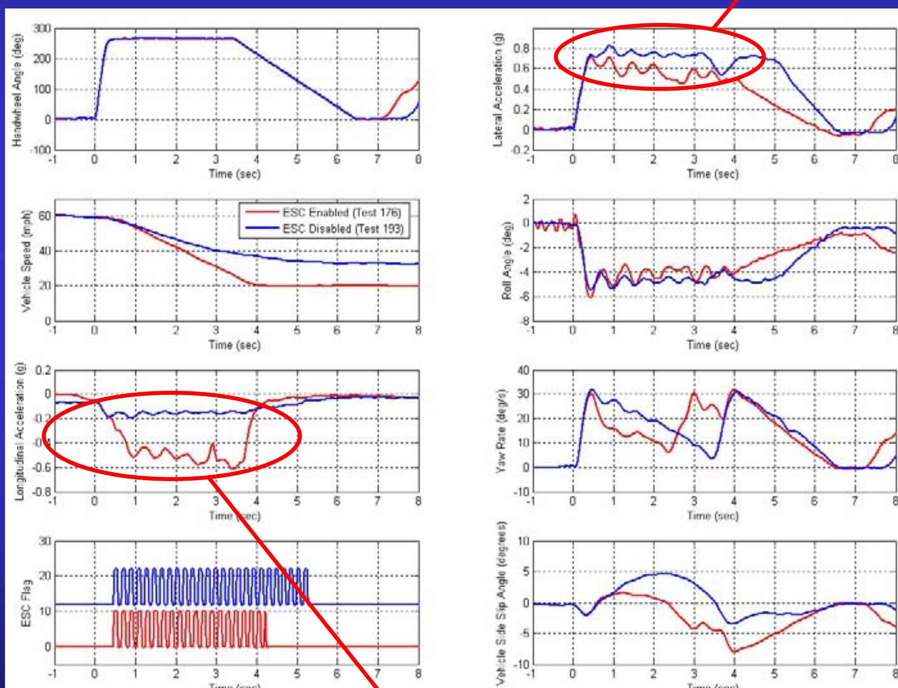
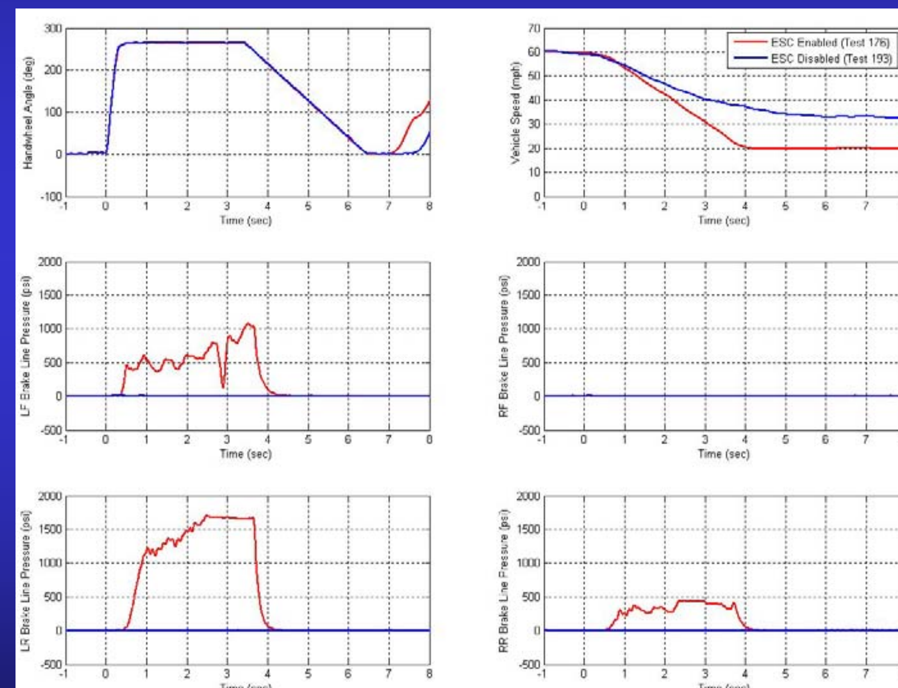
Noticeable reduction in AY





Significant increase in decel

Test Group 2
Performed With Four Human Drivers

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Maneuver	Throttle Application	Surface	Entrance Speed
Constant Radius Turn, 200-ft radius	Slowly Increasing	Dry Asphalt	Max Attainable
ISO 3888 Part 2 Double Lane Change (Modified)	Released at Entrance Gate	Wet Jennite	Max Attainable
ISO 3888 Part 2 Double Lane Change (Modified)	Released at Entrance Gate	Dry Asphalt	Max Attainable

Preliminary Results
Test Group 2

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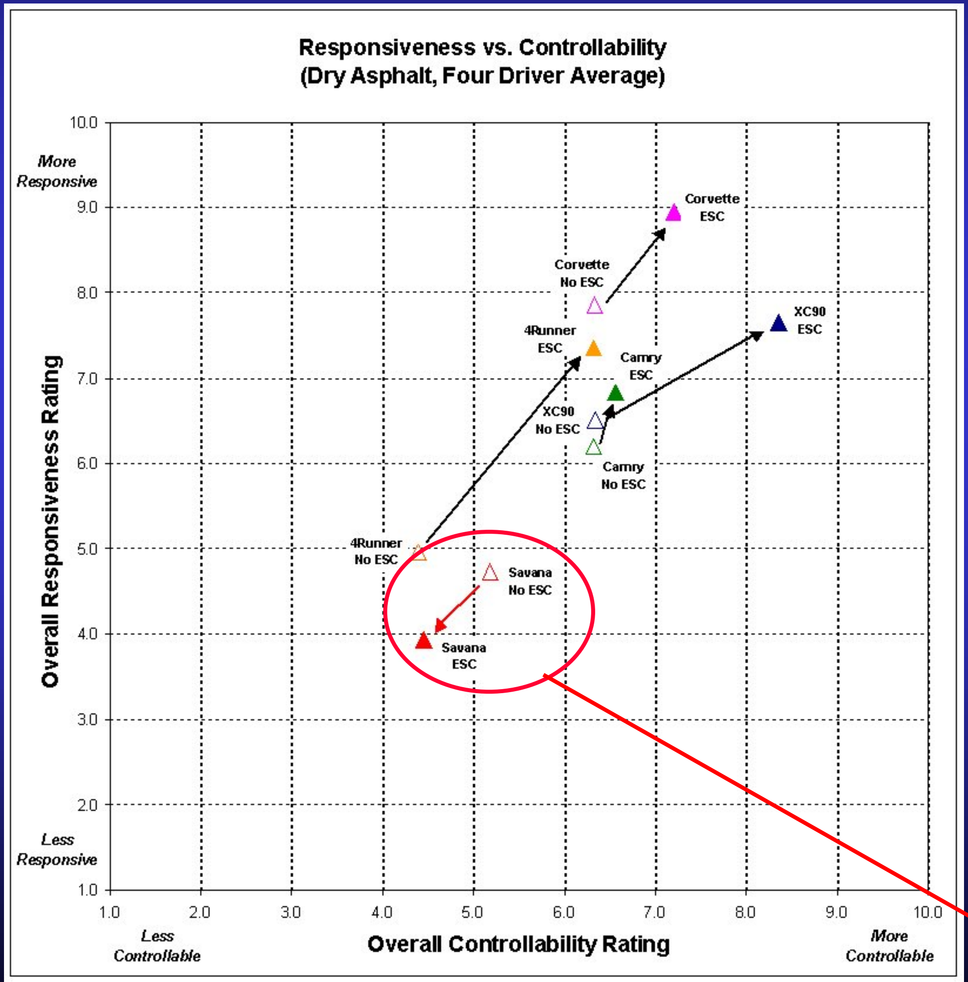
- **Utility of the subjective lane change data is a rank order of the vehicles**
  - **Results from a robust objective [handling] rating system should produce similar results**
- **Mixed results from the Group 2 lane changes**
  - **ESC effectiveness analyses require potentially large slip angles and yaw rates** *(i.e., when ESC is disabled)*
- **200-ft radius tests show significant limit handling improvements for some vehicles with ESC**

Sample Data
Test Group 2

People Saving People
http://www.nhtsa.dot.gov



<u>Overall Responsiveness</u>:

Avoidability; the overall ability for the vehicle to avoid an obstacle

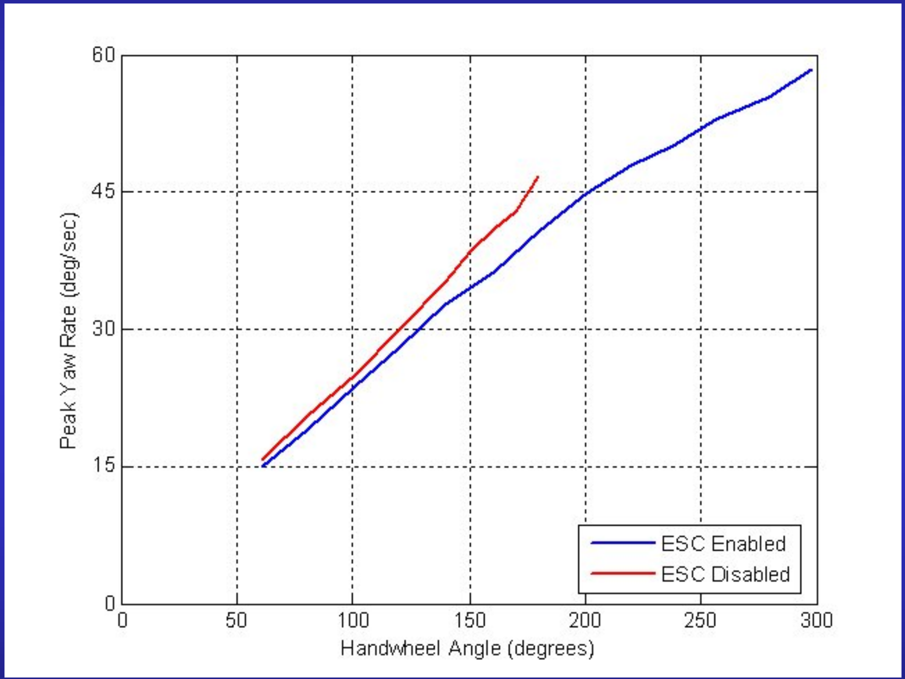
<u>Overall Controllability</u>:

Overall level of the driver's ability to maintain a desired path / complete the maneuver

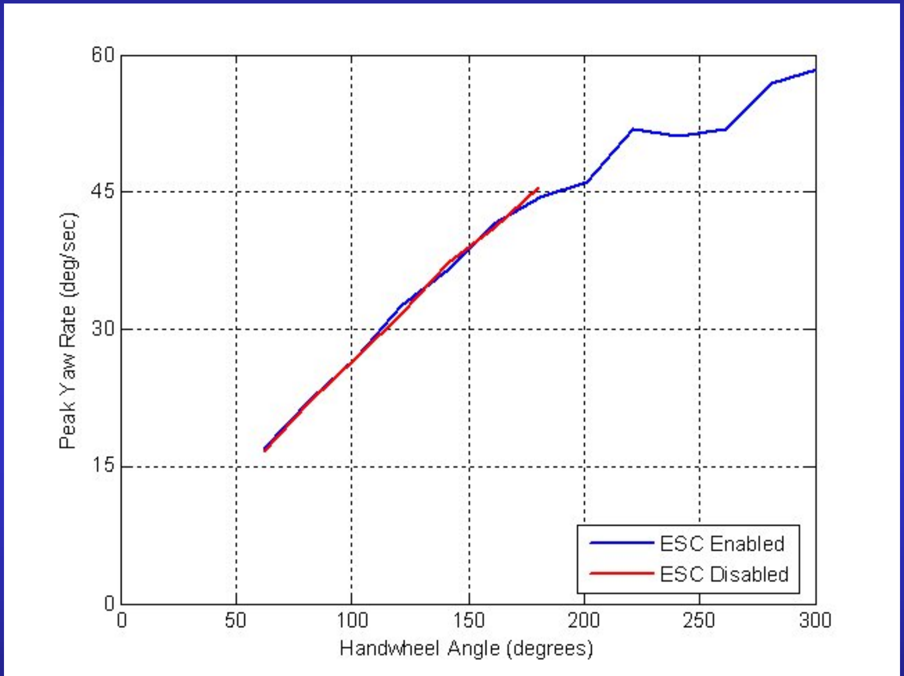
May be attributable to power steering pump catch

Sample Data
Test Group 3 (Toyota Camry)

People Saving People
http://www.nhtsa.dot.gov

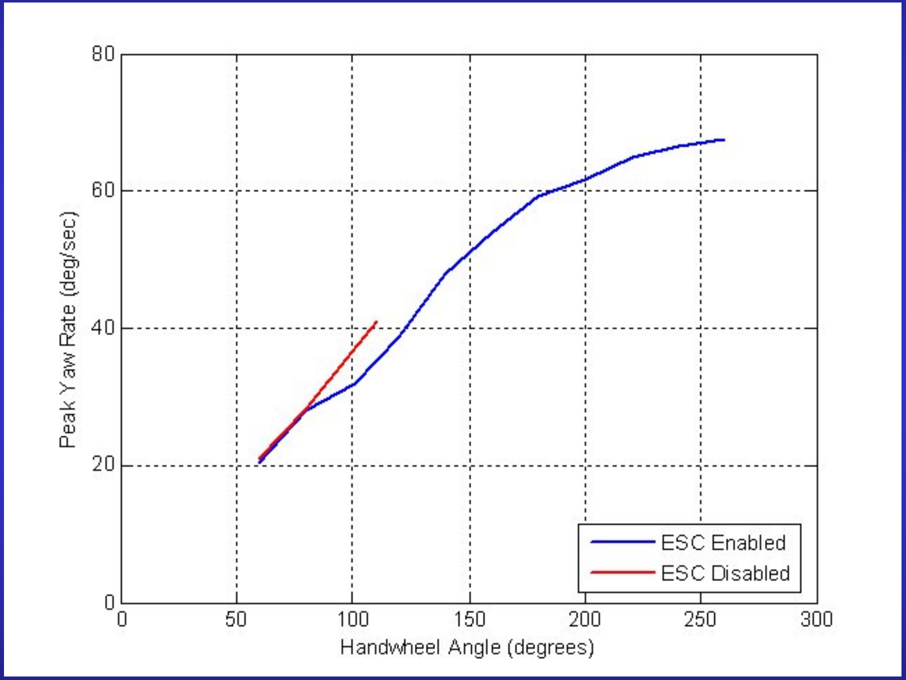


0.7 Hz SWD

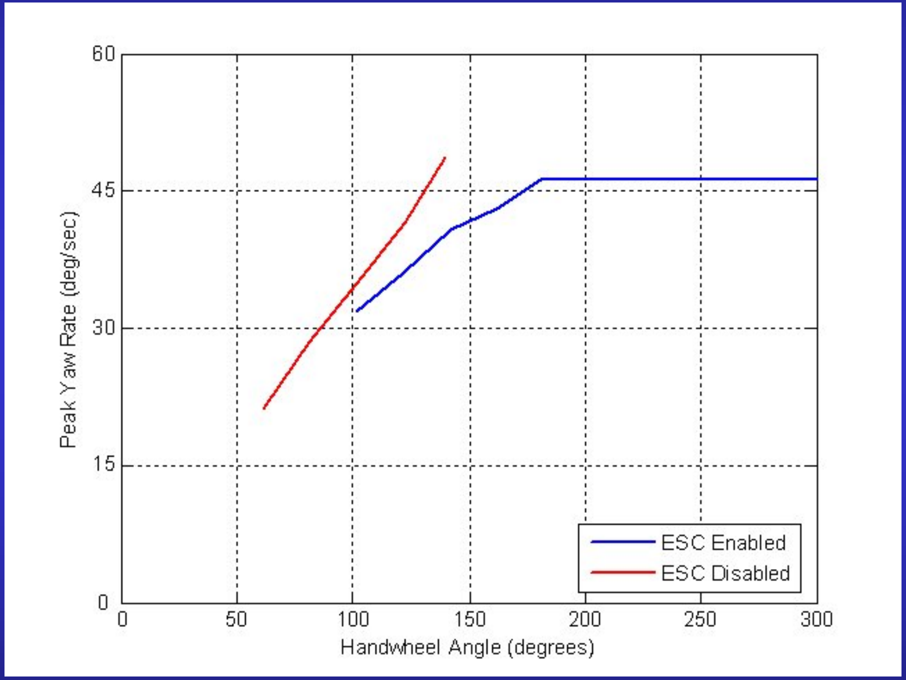


500 deg/sec YASR

Sample Data
Test Group 3 (Chevrolet Corvette)

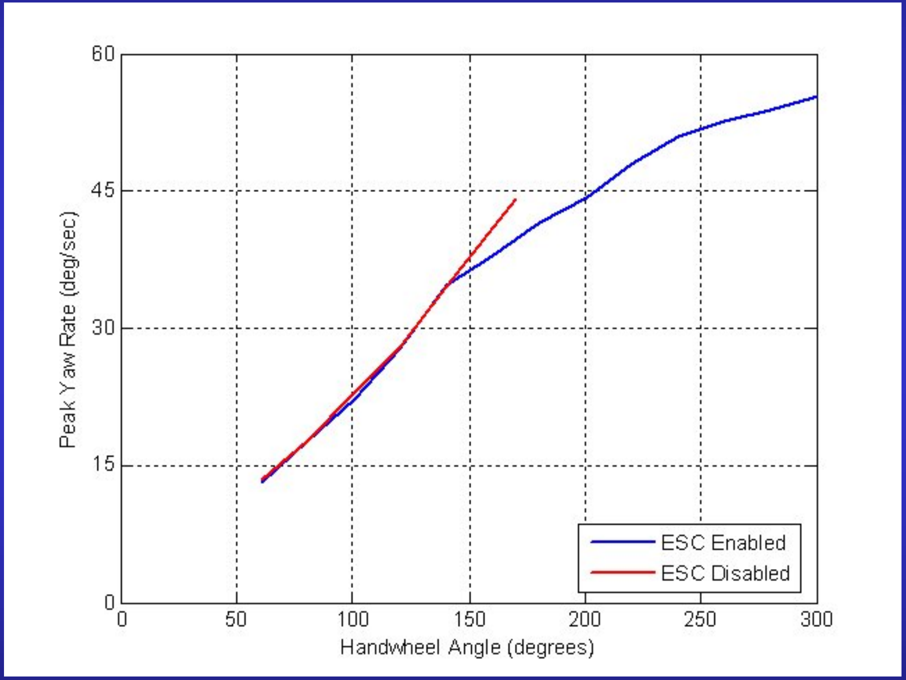


0.7 Hz SWD

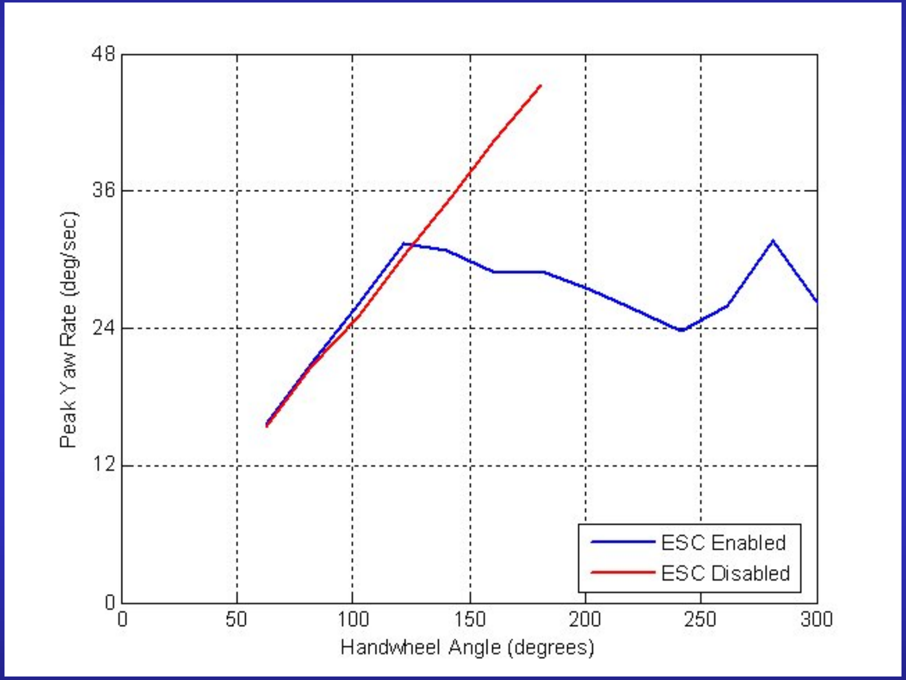


500 deg/sec YASR

Sample Data
Test Group 3 (Toyota 4Runner)

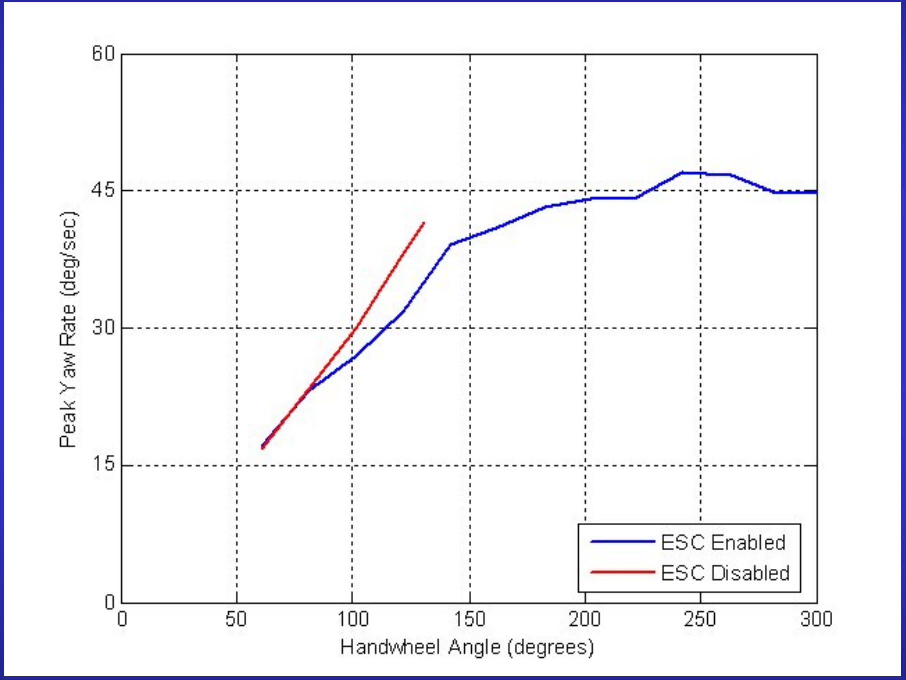


0.7 Hz SWD

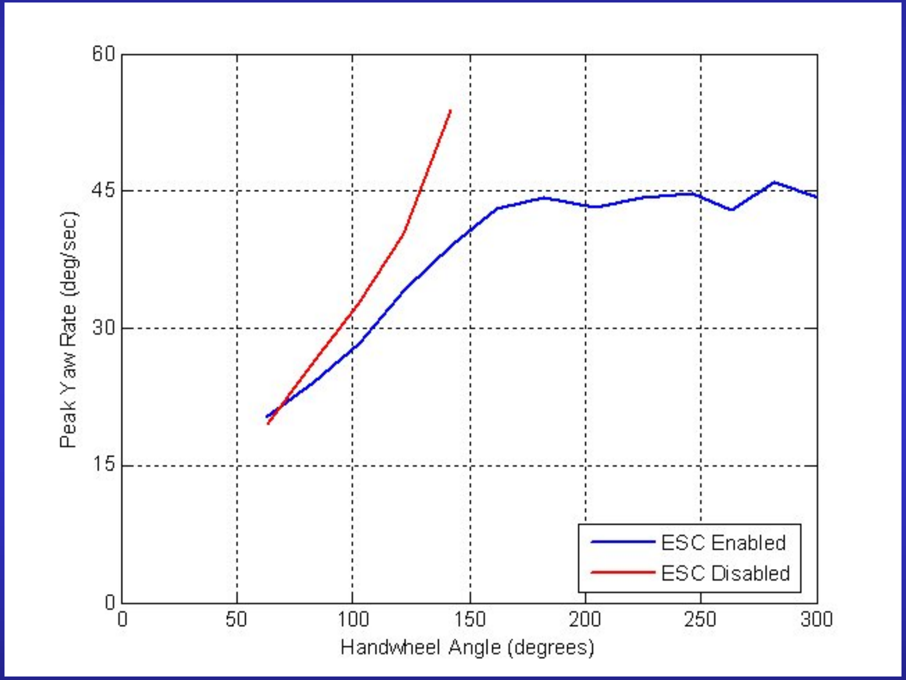


500 deg/sec YASR

Sample Data
Test Group 3 (Volvo XC90)



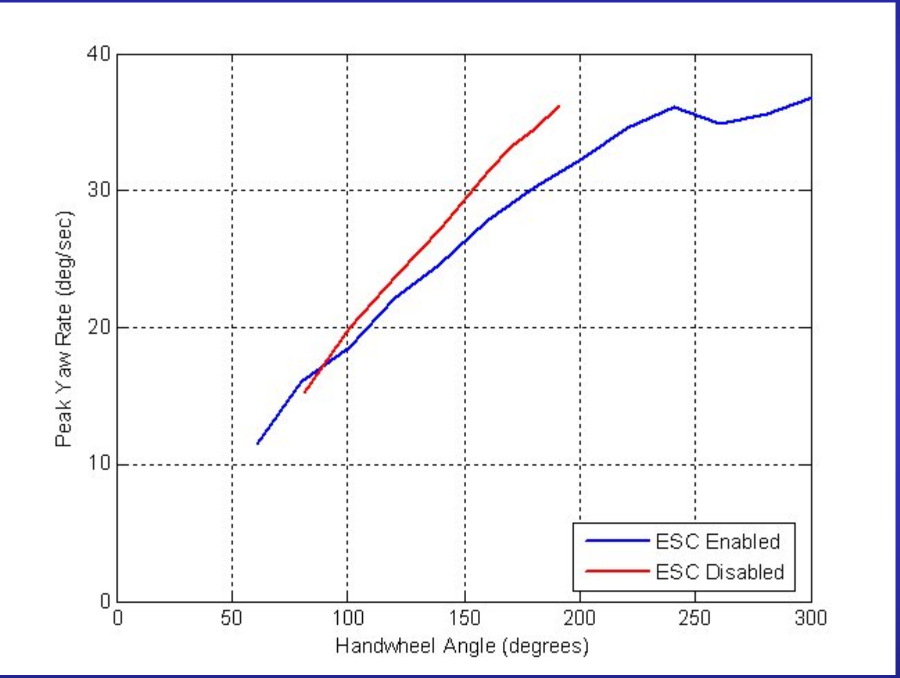
0.7 Hz SWD



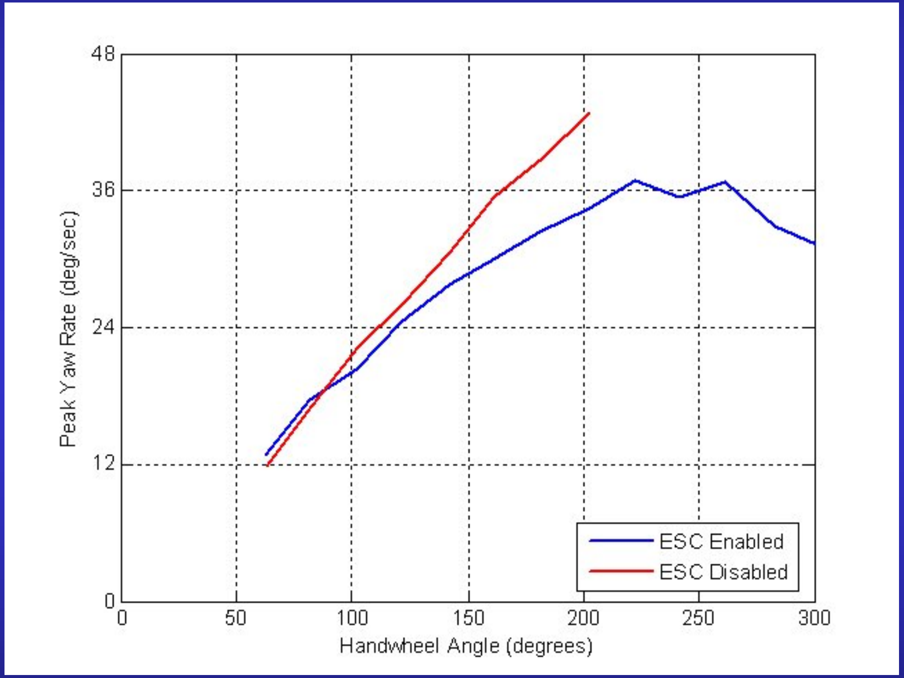
500 deg/sec YASR

Sample Data
Test Group 3 (GMC Savana)

People Saving People
http://www.nhtsa.dot.gov



0.7 Hz SWD



500 deg/sec YASR